



**Prepared in cooperation with the Bureau of Land Management, the National Park Service, and the U.S. Forest Service**

# **Geologic Map of the House Rock Valley Area, Coconino County, Northern Arizona**

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Pamphlet to accompany

**Scientific Investigations Map 3108**

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## Introduction

This geologic map is a cooperative effort of the U.S. Geological Survey (USGS), the Bureau of Land Management, the National Park Service, and the U.S. Forest Service to provide a geologic database for resource management officials and visitor information services. This map was produced in response to information needs related to a proposed withdrawal of three segregated land areas near Grand Canyon National Park, Arizona, from new hard rock mining activity. House Rock Valley was designated as the east parcel of the segregated lands near the Grand Canyon. This map was needed to provide connectivity for the geologic framework of the Grand Canyon segregated land areas.

This geologic map of the House Rock Valley area encompasses approximately 280 mi<sup>2</sup> (85.4 km<sup>2</sup>) within Coconino County, northern Arizona, and is bounded by longitude 111°37'30" to 112°05' W. and latitude 36°30' to 36°50' N. The map area is in the eastern part of the Arizona Strip, which lies within the southern Colorado Plateaus geologic province (herein Colorado Plateau). The Arizona Strip is the part of Arizona lying north of the Colorado River. The map is bound on the east by the Colorado River in Marble Canyon within Grand Canyon National Park and Glen Canyon National Recreation Area, on the south and west by the Kaibab National Forest and Grand Canyon National Game Preserve, and on the north by the Vermilion Cliffs Natural Area, the Paria Canyon Vermilion Cliffs Wilderness Area, and the Vermilion Cliffs National Monument. House Rock State Buffalo Ranch also bounds the southern edge of the map area.

The Bureau of Land Management Arizona Field Office in St. George, Utah, manages public lands of the Vermilion Cliffs Natural Area, Paria Canyon - Vermilion Cliffs Wilderness and Vermilion Cliffs National Monument. The North Kaibab Ranger District in Fredonia, Arizona, manages U.S. Forest Service land along the west edge of the map area and House Rock State Buffalo Ranch (U.S. Department of the Interior, 2006). Other lands include about 13 sections of Arizona State land, about ¾ of a section of private land along House Rock Wash, and about 1½ sections of private land at Cliff Dwellers Lodge, Vermilion Cliffs Lodge, and Marble Canyon, Arizona.

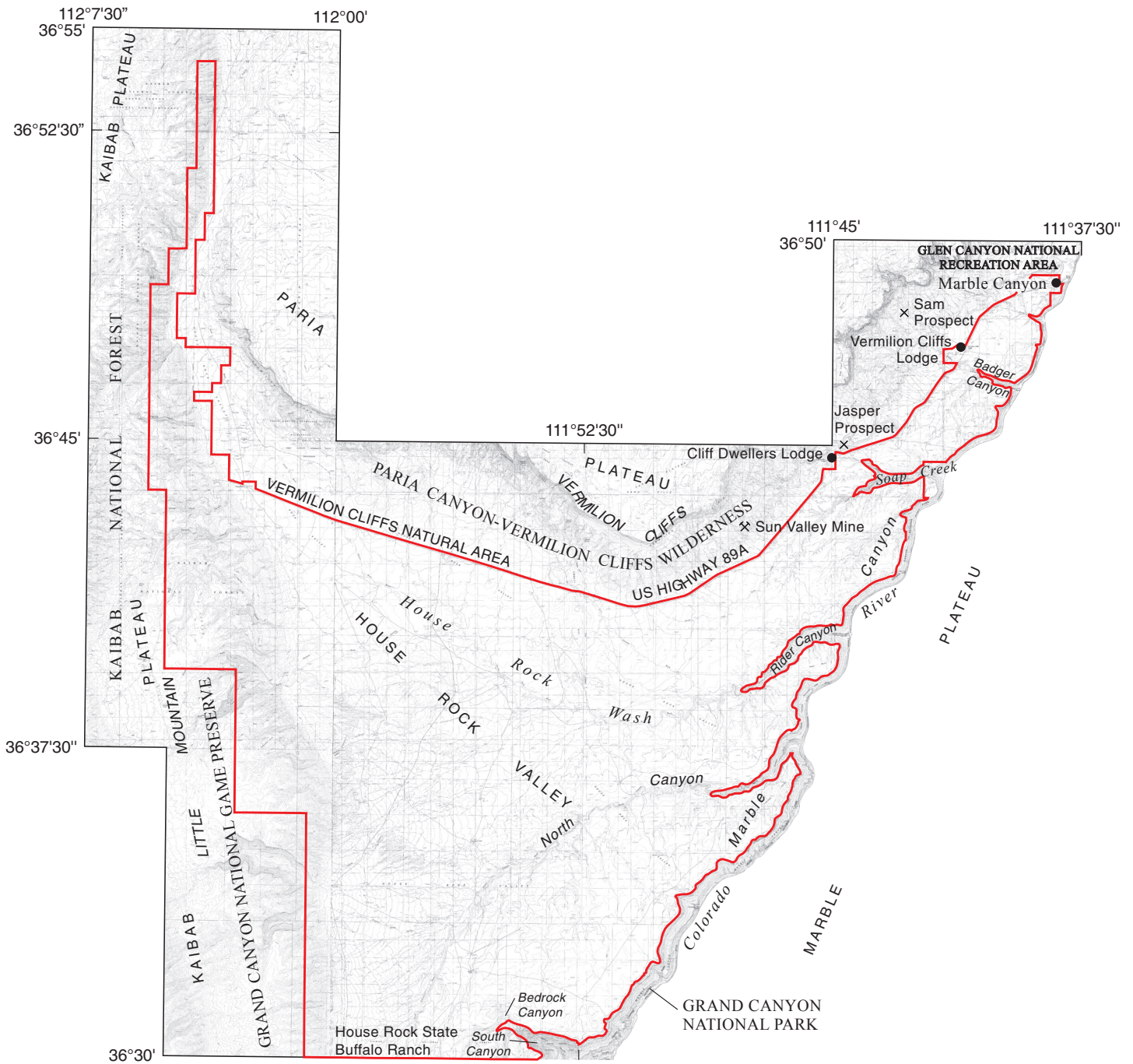
Landmark features within the map area include the Vermilion Cliffs, Paria Plateau, Marble Canyon, and House Rock Valley. Surface drainage in House Rock Valley is to the east toward the Colorado River in Marble Canyon. Large tributaries of Marble Canyon from north to south include Badger Canyon, Soap Creek, Rider Canyon, North Canyon, Bedrock Canyon, and South Canyon (fig. 1). Elevations range from about 2,875 ft (876 m) at the Colorado River in the southeast corner of the map to approximately 7,355 ft (2,224 m) on the east rim of Paria Plateau along the north-central edge of the map area.

Three small settlements are in the map area along U.S. Highway 89A, Cliff Dwellers Lodge, Vermilion Cliffs Lodge, and Marble Canyon, Arizona (fig. 1). The community of Jacob Lake is about 9 mi (14.5 km) west of House Rock Valley on the Kaibab Plateau. Lees Ferry is 5 mi (8 km) north of Marble Canyon and marks the confluence of the Paria and Colorado Rivers and the beginning of Marble Canyon. U.S. Highway 89A provides access to the northern part of the map area. Dirt roads lead south into House Rock Valley from U.S. Highway 89A and are collectively maintained by the Bureau of Land Management, the U.S. National Forest Service, and the Grand Canyon Trust.

House Rock Valley is one of the few remaining areas where uniform geologic mapping is needed for connectivity to the regional Grand Canyon geologic framework. This information is useful to Federal and State resource managers who direct environmental and land management programs that encompass such issues as range management, biological studies, flood control, water, and mineral-resource investigations. The geologic information will support future and ongoing geologic investigations and scientific studies of all disciplines within the Arizona Strip including the northeastern part of Grand Canyon National Park.

## Previous Work

Wilson and others (1960) compiled a geologic map of Coconino County at 1:375,000-scale using 1:24,000-scale reconnaissance maps by Dettmerman (1956a and b), Minard (1956a and b), Marshall (1956a and b), Peterson (1959; 1961), Peterson and Wells (1961), McQueen (1956), and Wells (1958; 1959; 1960). Wilson and others (1969) also compiled a geologic map of the state of Arizona from the same data with the addition of Phoenix (1963). House Rock Valley and Marble Canyon are included in a geologic map of the Marble Canyon 1° x 2° quadrangle by Haynes and Hackman (1978). Bush (1983) published a 1:62,500-scale map of the Vermilion Cliffs-Paria Canyon Wilderness Study Area. Cooley and others (1969) produced a regional geologic map east of Marble Canyon. A geologic map of the eastern Grand Canyon and vicinity, just south of House Rock Valley, was published by Huntoon and others (1996). Early digital 1:24,000-scale maps along the western and northwestern edge of House Rock Valley (Billingsley and others, 2001; Billingsley and Wellmeyer, 2001; and Billingsley and Hampton, 2001) were included as part of the Fredonia 30' x 60'



**Figure 1.** Index map of the House Rock Valley area showing physiographic, cultural, and geologic features mentioned in the text. Area outlined in red is parcel 3 of proposed segregated lands for mining withdrawal.

quadrangle, Arizona (Billingsley and others, 2008). The Quaternary geology, largely unmapped in earlier publications, has been updated to match the detail of mapped surficial units in the adjacent Fredonia 30' x 60' quadrangle, Arizona.

## Mapping Methods

Geologic mapping of the House Rock Valley area was produced using 1:24,000- and 1:12,000-scale color aerial photographs from surveys flown in 1981 and 1986 respectively, courtesy of the U.S. Forest Service, and 1:24,000-scale color aerial photographs from surveys flown in 2005 by the Bureau of Land Management. Aerial photogeology was compiled onto USGS 1:24,000-scale topographic maps. The map area was field checked to verify surficial and bedrock geology, structure, and map-unit descriptions.

Many of the Quaternary alluvial and eolian deposits are lithologically and geomorphically similar to each other and to units in the adjoining Fredonia 30' x 60' quadrangle. These units were mapped almost entirely by photogeologic methods. In most areas, lithology, stratigraphic position, and amount of erosional degradation were used to correlate relative age of the alluvial and eolian deposits. Not all surficial deposits within Marble Canyon were field checked. Geologic information along the Colorado River represents photogeology interpretation with some field verification by way of canyon rim view points.

The digital geodatabase was created using ESRI (Environmental Systems Research Institute) ArcGIS. Field sheets were scanned and then brought into ArcMap for georeferencing. Geologic features were then digitized, symbolized, and cross-checked against the original field sheets.

## Geologic Setting

The House Rock Valley area is characterized by nearly flat lying to gently dipping and sedimentary strata that overlie tilted Proterozoic strata or metasedimentary and igneous rocks, similar to those exposed at the bottom of Grand Canyon south of the map area (Timmons and others, 2007). The East Kaibab Monocline elevates strata up-to-the-west along the western edge of House Rock Valley characterized by eastward-dipping strata. Devonian and Cambrian strata are exposed in Marble Canyon and Grand Canyon just south of the map and are likely present in the subsurface of House Rock Valley. Younger Paleozoic rocks, ranging from Permian through Mississippian age, are exposed in the walls of Marble Canyon from the south edge of the map north to Marble Canyon, Arizona. Mesozoic sedimentary rocks are exposed in the northern part of the map where resistant Lower Jurassic sandstones form the Vermilion Cliffs that mark the southern edge of the Paria Plateau. Late Cenozoic landslides and talus deposits are present along the Vermilion Cliffs below the Paria Plateau and as isolated deposits in Marble Canyon. Surficial fluvial and eolian deposits are scattered throughout the map, especially along House Rock Wash in the northwestern quarter of the map and on Paria Plateau.

House Rock Valley is located between the Marble Plateau and the Kaibab Plateau within an ill-defined broad basin that gently plunges north towards the Paria Plateau and Utah. The Paria Plateau Syncline, a very open fold is suggested on the Marble Canyon map of Haynes and Hackman (1978) and shown by Bush (1983). The Mesozoic rocks that form the Paria Plateau once covered all of House Rock Valley and the adjacent Kaibab and Marble Plateaus. Mesozoic strata eroded off the elevated Kaibab and Marble Plateaus first while House Rock Valley was still an ancestral Paria Plateau.

Cenozoic erosion slowly removed the Mesozoic rocks of the ancestral Paria Plateau from House Rock Valley. Strike-valley drainages developed in the soft Triassic rocks below the eroding Vermilion Cliffs around the Paria Plateau. As the Vermilion Cliffs eroded northward, each successive strike-valley drainage became entrenched into the resistant Permian Kaibab Formation leaving a succession of canyon drainages to the Colorado River. Thus, each successive canyon becomes smaller and smaller northward to Marble Canyon, Arizona, as the Vermilion Cliffs continued to retreat to their present position. (Billingsley and Breed, 1973).

The principal tectonic feature is the north-trending, east-dipping, upper and lower segments of the East Kaibab Monocline (Billingsley and Hampton, 2001; Billingsley and Wellmeyer, 2001; Billingsley and others, 2001; Billingsley and others, 2008). The upper segment of the East Kaibab Monocline is mostly west of the map area except in the upper part of House Rock Valley. The lower segment elevates Little Mountain as part of the Kaibab Plateau. The upper and lower segments of the East Kaibab Monocline merge into one monocline just south of the map area and before reaching Grand Canyon. Erosion of the Grand Canyon south of the map area has exposed the fault complex beneath the East Kaibab Monocline and provides a window into the deep structural complexity of monoclines in this part of the Colorado Plateau (Timmons and others, 2007). The lower segment of the East Kaibab Monocline forms the structural boundary

between House Rock Valley and Kaibab Plateau in the southern two-thirds of the map area and in the northern one-third where the upper and lower segments of the East Kaibab Monocline form one monocline.

The Kaibab Formation (Cisuralian—the lower Permian is called Cisuralian) forms most of the surface bedrock of House Rock Valley. A few scattered outcrops of the Moenkopi Formation (Middle to Lower Triassic) are preserved under a mantle of older alluvial fan deposits along the west edge of the map area. The Paria Plateau is composed of Triassic and Jurassic strata capped by the cliff-forming Navajo Sandstone (Lower Jurassic to Triassic(?)). The bedrock surface of the Paria Plateau is mantled by extensive Holocene eolian sand deposits.

The broad, elongated Echo Anticline forms the Marble Plateau east of Marble Canyon and east of the map area. Here Mesozoic and Paleozoic strata dip less than 1 to 2 degrees west and northwest toward Marble Canyon and House Rock Valley from a central high area about 7 mi (11 m) east of the map area. The Echo Anticline plunges gently southeast toward the Painted Desert near Cameron, Arizona, and northeast toward Lees Ferry, Arizona (Haynes and Hackman, 1978).

## Paleozoic Rocks

The erosion of Marble Canyon has exposed about 2,400 ft (732 m) of Paleozoic rocks along the southeastern edge of the map area. These Paleozoic rocks are likely present in the subsurface of House Rock Valley, Paria Plateau, and Kaibab Plateau with variable facies and thickness changes. There is a gradual thinning of most units toward the east and a gradual thickening toward the west of the map area. The exposed Paleozoic rocks are, from oldest to youngest, the Redwall Limestone (Upper and Lower Mississippian), the Surprise Canyon Formation (Upper Mississippian), the lower Supai Group, undivided (Upper, Middle, and Lower Pennsylvanian, Upper Mississippian, and Cisuralian), the Esplanade Sandstone (Cisuralian) of the upper Supai Group, the Hermit Formation (Cisuralian), the Coconino Sandstone (Cisuralian), the Toroweap Formation (Cisuralian), and the Kaibab Formation (Cisuralian). Paleozoic rocks not exposed in the map area but are likely beneath the Redwall Limestone are, from oldest to youngest, the Tapeats Sandstone (Middle and Lower(?) Cambrian), Bright Angel Shale (Middle and Lower(?) Cambrian), Muav Limestone (Middle Cambrian), and the Temple Butte Formation (Upper and Middle Devonian).

## Mississippian

The Redwall Limestone (**Mr**) forms a 500 to 550 ft (152 to 168 m) gray cliff in the narrow depths of Marble Canyon at the southeastern edge of the map area. The Redwall Limestone gradually thins to the east and thickens west of Marble Canyon and unconformably overlies either the Temple Butte Formation or the Muav Limestone where the Temple Butte is locally missing.

Overlying the Redwall Limestone is the Surprise Canyon Formation (**Ms**). This unit is not widespread because it is present only in local shallow paleovalleys less than 40 ft (12 m) deep or fills paleokarst caves eroded into the top part of the Redwall Limestone. The Surprise Canyon Formation gradually thickens toward the west and thins east of the map area.

## Undivided Pennsylvanian

The undivided lower Supai Group (**IPms**) includes, in ascending order, the Watahomigi Formation (Upper Mississippian and Middle Pennsylvanian), the Manakacha Formation (Middle Pennsylvanian), and the Wescogame Formation (Upper Pennsylvanian), an alternating sequence of continental deposits deltaic sandstone and siltstone and minor limestone. The upper Supai Group consists of the Esplanade Sandstone (Cisuralian). The Supai Group as a whole unconformably overlies the Redwall Limestone or the Surprise Canyon Formation, where present, and maintains a general thickness of about 800 ft (244 m) throughout the subsurface of the map area.

## Permian

The Esplanade Sandstone (**Pe**) of the upper Supai Group forms a prominent light-red sandstone cliff in Marble Canyon 350 to 400 ft (107 to 122 m) thick. It gradually thins east and south and thickens north of the map area.

Unconformably overlying the Esplanade Sandstone is the slope-forming red siltstone and sandstone sequence of the Hermit Formation (Cisuralian). Stream channels eroded into the underlying Esplanade Sandstone are as much as 10 ft (3 m) deep. The Hermit Formation (**Ph**) generally thins from north to south in Marble Canyon from about 700 ft (213 m)

near Badger Canyon to about 400 ft (122 m) near Bedrock Canyon. The Hermit Formation generally thins east and south of House Rock Valley and thickens north and west. A sharp planar erosional contact separates the red Hermit Formation from the overlying buff-white Coconino Sandstone.

The Coconino Sandstone (Cisuralian) forms a tan-white 600 ft (183 m) cliff in the southern part of Marble Canyon and rapidly thins northward to less than 30 ft (9 m) at Marble Canyon, Arizona. The Coconino Sandstone (**Pc**) pinches out north of the map area, gradually thins west and east, and rapidly thickens south and southwest. The Coconino Sandstone is a tongue of the Seligman Member of the Toroweap Formation in the western and northern region of the Grand Canyon (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; Billingsley and others, 2000; and Billingsley and Wellmeyer, 2003) and part of an upper tongue of the Toroweap Formation in Utah (Blakey, 1996) but the name Coconino Sandstone is a well-established term in Grand Canyon nomenclature and forms a distinct mappable unit throughout the region. The Coconino Sandstone forms an important groundwater unit locally known as the “C” aquifer.

The Toroweap Formation (Cisuralian) includes, in ascending order, the Seligman (**Pts**), Brady Canyon (**Ptb**), and Woods Ranch (**Ptw**) Members as defined by Sorauf and Billingsley (1991). The Seligman is composed mainly of siltstone and sandstone, the Brady Canyon is limestone, and the Woods Ranch is gypsiferous siltstone and gypsum. All three members are mappable along the western edge of the map area. The members are not mapped in parts of Marble Canyon either because the Seligman and Brady Canyon Members are too thin to show at map scale or all three members are unrecognizable due to an abrupt east-west facies change where the Toroweap Formation (**Pt**) forms a brown cliff of calcareous sandstone. The Toroweap Formation overlies the Coconino Sandstone and undergoes a substantial west-to-east facies change along a zone that roughly parallels the Colorado River in Marble Canyon. The Toroweap Formation maintains a general thickness of about 200 ft (60 m) throughout the map area. The Toroweap Formation gradually thins east, north, and south of the map area and thickens west.

The Kaibab Formation (Cisuralian) forms the gray rim of Marble Canyon and the surface bedrock for much of House Rock Valley. In places it is covered by remnants of red siltstone and sandstone of the Moenkopi Formation (Middle(?) to Lower Triassic) or surficial deposits. The Kaibab Formation is divided into, in ascending order, the Fossil Mountain Member (**Pkf**) and the Harrisburg Member (**Pkh**) as defined by Sorauf and Billingsley (1991). A gradational and arbitrary boundary separates the ledge- and cliff-forming Fossil Mountain Member from the overlying slope- and ledge-forming Harrisburg Member. The Fossil Mountain Member contains brachiopod, sponge, crinoids, and trilobite fossils as well as abundant chert beds, lenses, and nodules. The Harrisburg Member is primarily a sandy limestone or calcareous sandstone that locally contains some mollusk fossils and brecciated chert beds. The Kaibab Formation is typically weathered or stained dark-gray or black by manganese oxide in canyon outcrops. The Fossil Mountain and Harrisburg Members undergo a gradual west to east facies change across the map area making it increasingly difficult to distinguish one member from the other based on lithology or topographic expression. The Kaibab Formation is approximately 240 to 330 ft (73 to 100 m) thick throughout the map area and gradually thins east, southeast, south, and southwest and thickens west and northwest.

A regional unconformity separates the gray Permian Kaibab Formation from the overlying red Triassic Moenkopi Formation with a general relief of less than 10 ft (3 m). The unconformity is commonly recognized by a lithology and color change from grayish-white sandy limestone of the Kaibab Formation to red, thin-bedded, sandstone and siltstone of the Moenkopi Formation. Erosional depressions and channels in the upper Kaibab were subsequently filled with angular and subangular chert and sandstone conglomerate or breccia deposits derived from erosion of the Kaibab Formation. These deposits form thin lenticular basal beds of the Moenkopi Formation.

## Mesozoic Rocks

Late Cenozoic erosion has exposed about 3,000 ft (914 m) of Mesozoic rock strata in the Vermilion Cliffs along the northern edge of the map area. Some of the Mesozoic strata undergo rapid facies and thickness changes in all directions beneath Paria Plateau based on exposures along the Vermilion Cliffs and the Echo Cliffs east of the map area. The Mesozoic rocks are, in ascending order, the Moenkopi Formation, (Middle(?) and Lower Triassic), the Chinle Formation (Upper Triassic), and the Glen Canyon Group comprised of the Moenave Formation (Lower Jurassic), the Kayenta Formation (Lower Jurassic), and the Navajo Sandstone (Lower Jurassic).

## Triassic

Overlying the Permian Kaibab Formation is a sequence of red sandstone ledges and siltstone slopes of the Moenkopi Formation. These rocks are preserved as scattered outcrops in the western edge of House Rock Valley and along the base of the Vermilion Cliffs. Prior to Cenozoic erosion, the Moenkopi Formation covered the entire House Rock Valley area as

much as 460 ft (140 m) thick (Phoenix, 1963). The Moenkopi Formation gradually thickens northwest and thins southeast of the map area (Billingsley and Workman, 2000; Billingsley and others, 2008).

On this map the Moenkopi Formation is subdivided into three map units using the subdivisions of Stewart and others (1972). In ascending order they are the undivided lower members ( $\overline{\text{Rmlm}}$ ; includes the middle red, Virgin Limestone, and lower red members), the Shnabkaib Member ( $\overline{\text{Rms}}$ ), and the upper red member ( $\overline{\text{Rmu}}$ ). The siltstones and sandstones of the Moenkopi Formation were deposited as shallow tidal flats and fluvial floodplains that drained northwest toward southern Utah (Blakey and Ranney, 2008). This coastal setting was later followed by a general northwesterly fluvial drainage system that deposited the overlying Chinle Formation and formed an erosional unconformity between the Moenkopi and Chinle Formations. At this time, channels up to 30 ft (10 m) eroded into the Moenkopi Formation. Some channels are as much as 180 ft (55 m) deep near Cliff Dwellers Lodge, and Lees Ferry, Arizona. Post Moenkopi erosion removed much of the upper red member and part of the Shnabkaib Member from Cliff Dwellers Lodge to Marble Canyon, Arizona. This unconformity is known as the T-3 unconformity (Blakey, 1994). The eroded stream valleys began to accumulate mud, sand and gravel that form the Shinarump Member of the Chinle Formation.

The Chinle Formation, the most colorful formation in the map area, is subdivided into three mappable units along the Vermilion Cliffs. In ascending order they are, the Shinarump Member ( $\overline{\text{Rcs}}$ ), the Petrified Forest Member ( $\overline{\text{Rcp}}$ ), and the Owl Rock Member ( $\overline{\text{Rco}}$ ) as defined by Akers and others (1958) and Repenning and others (1969). The tan and white conglomeratic sandstone beds of the Shinarump Member contain numerous petrified log and wood fragments and lenses of well-rounded quartzite and chert pebbles. Thickness of the Shinarump Member ranges from 0 to 180 ft (0 to 55 m) due to channel fill and pinch out (Phoenix, 1963). The contact between the cliff-forming Shinarump and overlying slope-forming Petrified Forest Member is gradational marked by the topographic cliff-slope break, a lithology change, and/or color change.

The Petrified Forest Member of the Chinle Formation forms the multicolored blue, red, white, and grayish-green mudstone hills of the Painted Desert badlands along the base of the Vermilion Cliffs north of U.S. Highway 89A. The Petrified Forest Member maintains a uniform thickness of 600 to 625 ft (182 to 190 m) but thins toward Lees Ferry, Arizona.

Overlying the Petrified Forest Member is the Owl Rock Member of the Chinle Formation with a variable thickness of 150 to 200 ft (46 to 60 m). The Owl Rock Member consists of an interbedded sequence of greenish-gray, ledge- and slope-forming, siliceous limestone and calcareous siltstone observed near the base of the Vermilion Cliffs that is mostly covered by landslide or talus debris or eolian sand deposits. The contact between the Petrified Forest and Owl Rock Members is generally marked at the lowest gray cherty limestone bed of the Owl Rock Member.

The contact of the Upper Triassic Owl Rock Member with the overlying Jurassic Moenave Formation is unconformable and marked by a sharp contrast in lithology and color change from gray mudstone, siltstone, and limestone of the Owl Rock to orange-red fluvial sandstone of the Moenave. This regional unconformity is known as the J-O unconformity (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979). The Owl Rock gradually thins northward along the Vermilion Cliffs to Lees Ferry, Arizona.

The soft mudstone and siltstone of the Petrified Forest and Owl Rock Members of the Chinle Formation are easily eroded. The removal of these soft rocks allows erosional undercutting of the more resistant cliff-forming strata above (Moenave Formation, Kayenta Formation, and Navajo Sandstone). This leads to cliff failure along fractures and joints creating landslide blocks that gradually slide downward and rotate backward against the parent cliff. This action is amplified during wetter climate conditions.

## Jurassic

Overlying the Owl Rock Member of the Chinle Formation is the orange-red sandstone and siltstone sequence of the Moenave Formation ( $\overline{\text{Jm}}$ ). The Moenave Formation includes only the Dinosaur Canyon Member as described by Colbert and Mook (1951). The Springdale Sandstone was originally described by Gregory (1950) as part of the Chinle Formation and redefined as an upper member of the underlying Moenave Formation (Averitt and others, 1955; Harshbarger and others, 1958; Stewart and others, 1972; Sargent and Philpott, 1987; Billingsley and others, 2004). More recently, the Springdale Sandstone has been reassigned to the basal part of the Kayenta Formation (Biek and others, 2007) on the basis of paleontological data and a prominent Jurassic unconformity at the base of the Springdale Sandstone (Blakey, 1994; Marzolf, 1991; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007). Thus, the Moenave Formation now includes only the original Dinosaur Canyon Member and is herein mapped as the Moenave Formation. The Moenave is largely covered by talus and rock-fall or landslide deposits along the Vermilion Cliffs north and west of U.S. Highway 89A. Overall, the Moenave Formation ranges from 180 to 220 ft (55 to 67 m) thick within the map area and gradually thins north and northeast of the map area.

The Kayenta Formation unconformably overlies the Moenave Formation. This unconformity is the sub-Kayenta

Formation unconformity (J-sub-K) as defined by Riggs and Blakey (1993) and Blakey (1994). Erosional relief is generally less than 6 ft (2 m) but can be as much as 50 ft (15 m) in the map area (Phoenix, 1963). The Kayenta Formation (Jk) includes, in ascending order, the Springdale Sandstone Member (Jks) and an upper siltstone and sandstone unit (Blakey 1994). The Springdale Sandstone Member forms a dark orange-red, thick-bedded sandstone cliff about 90 to 220 ft (27 to 67 m) thick. This layer is overlain by the a purple-red, slope-forming siltstone and sandstone sequence upper Kayenta Formation about 180 to 225 ft (55 to 68 m) thick along the Vermilion Cliffs to Lees Ferry, Arizona. The upper purple-red siltstone/sandstone sequence undergoes a facies change northward into a series of light-red sandstone cliffs and small red siltstone slopes at Lees Ferry, Arizona.

The Jurassic Navajo Sandstone (Jn) is a red and white, cliff-forming, crossbedded eolian sandstone that maintains a general thickness of about 1,750 ft (534 m) along the Vermilion Cliffs. This unit forms the surface bedrock of the Paria Plateau. Just northwest of the map area, the beveled surface between the Navajo Sandstone and Page Sandstone, or the Navajo Sandstone and Carmel Formation, forms an erosional unconformity known regionally as the J-1 and J-2 unconformity (Pipiringos and O'Sullivan, 1978; Blakey, 1994). The Page Sandstone may be present on the Paria Plateau in the map area but it is difficult to identify because it is similar in lithology, color, and topographic expression to the Navajo Sandstone. The Carmel Formation is present on the Paria Plateau just north of the map area. For this reason the Page Sandstone, if present, is included within the upper part of the Navajo Sandstone.

## Surficial Deposits

### Holocene and Pleistocene Deposits

Quaternary alluvial and eolian deposits cover much of the bedrock in the House Rock Valley area. Alluvial stream (Qs), flood-plain (Qf), terrace (Qa1, Qa2, and Qa3), alluvial fan (Qa1, Qa2, Qa3, and Qa4), terrace-gravel (Qg1, Qg2, Qg3, and Qg4), ponded sediments (Qps), and valley alluvial (Qv) deposits of Holocene and Pleistocene age mantle parts of the Moenkopi and Kaibab Formations in the western and northern part of House Rock Valley. The alluvial deposits are locally derived from Paleozoic bedrock outcrops of the elevated Kaibab Plateau west of House Rock Valley and from Mesozoic bedrock outcrops of the Vermilion Cliffs north of House Rock Valley and along the Vermilion Cliffs. Extensive eolian deposits cover parts of the Paria Plateau and the northwestern part of House Rock Valley and are often mixed with alluvial (Qae) deposits. Sand eroded or weathered from the Navajo Sandstone and other Mesozoic strata becomes the primary source of young sand sheet and sand dune (Qd), young parabolic dune (Qdp), and young eolian sand sheet (Qes) deposits on the Paria Plateau and in upper House Rock Valley. Eolian and fluvial deposits in House Rock Valley are gradually eroded and transported down House Rock Wash into Rider Canyon and then to the Colorado River in Marble Canyon. The northwest part of House Rock Valley is partially filled with alluvial and eolian deposits, perhaps as much as 65 ft (22 m) thick based on exposures where House Rock Wash has eroded through the alluvium to bedrock.

Other surficial deposits within the map area include landslide (Ql) and talus and rock-fall (Qtr) deposits. These deposits are mainly exposed below the Vermilion Cliffs and below the rim of Marble Canyon and its tributary canyons. Fluvial stream (Qs), flood-plain (Qf), ponded (Qps), stream terrace-gravel (Qg1-Qg4), mixed alluvium and sand (Qae), and valley-fill (Qv) deposits are also shown. Man-made diversion dams, stock tanks, gravel pits, and mines (Qaf) are mapped to show the human impact upon the landscape.

Unconsolidated and partly consolidated terrace- gravel (Qg4) deposits rest unconformably on beveled surfaces of the Moenkopi and Kaibab Formations near Marble Canyon, Arizona. These gravel deposits are as much as 15 ft (4.5 m) thick and are comprised of well-rounded pebbles and cobbles of chert, quartzite, sandstone, limestone, and fossil wood fragments deposited by an ancestral Colorado River. These Colorado River gravels are as much as 1,000 ft (304 m) above the modern Colorado River on the east rim of Marble Canyon just southeast of Badger Canyon and are likely the oldest ancestral Colorado River gravel deposits in the Marble Canyon area.

## Structural Geology

Structural deformation of the Paleoproterozoic, Mesoproterozoic, and Neoproterozoic rocks at the bottom of Grand Canyon just south of the House Rock Valley area are well described by Timmons and others (2005; 2007). These rocks may be present in the subsurface of House Rock Valley and the Kaibab Plateau areas.

The largest high-angle to nearly vertical normal-fault separations in the Proterozoic basement rocks set the stage for



further structural deformation of the younger Mesozoic and Paleozoic strata as northeast to east-dipping sinuous monoclines along the western edge of the map area. Compressional folding of Paleozoic and Mesozoic rocks along these reactivated Proterozoic high-angle faults began in early Tertiary and Late Cretaceous time—a period known as the Laramide Orogeny that lasted from about 80 to 40 Ma. Concurrent and subsequent erosion has removed much of the Mesozoic strata that once covered the entire map area (Huntoon, 1990; 2003; Huntoon and others, 1996; Timmons and others, 2007).

The lower and upper segments of the East Kaibab Monocline have elevated the landscape west of the monocline to form the topographic highlands of Little Mountain between these monocline segments as part of the Kaibab Plateau (fig. 1). The upper and lower segments of the East Kaibab Monocline join together to become one monocline that extends north into Utah and southeast into the eastern Grand Canyon (Timmons and others, 2007). The East Kaibab Monocline forms the structural boundary between the Kaibab Plateau and House Rock Valley in the northern part of the map area. Strata along the monocline dip east and northeast between 20° and 35° with the steepest dip in the lower part of the fold along the western edge of the map area (Billingsley and others, 2001; Billingsley and Hampton, 2001; Billingsley and Wellmeyer, 2001; Billingsley and others, 2008). Vertical relief of Paleozoic strata along the lower segment of the East Kaibab Monocline and Little Mountain averages approximately 1,300 ft (396 m) up-to-the-west along the southwestern edge of the map area and approximately 1,800 ft (550 m) along the northwestern edge.

East of House Rock Valley is the Marble Plateau, a broad, gentle, elongated, doubly plunging extension of the Echo Anticline. The Echo Anticline forms the eastern boundary of Marble Plateau about 7 mi (11 km) east of the map area (Haynes and Hackman, 1978). Remnants of the Moenkopi and Chinle Formations are scattered at various locations on the Marble Plateau documenting that lower Mesozoic strata once covered it.

Mesozoic and Paleozoic strata in House Rock Valley and the Paria Plateau area gently dip northeast from the Kaibab Plateau and northwest from the Marble Plateau to form the subtle, gentle, down warped Paria Plateau Syncline (Bush, 1983). The rocks of House Rock Valley and Paria Plateau are so gently warped and structural control is so sparse that the validity of the broad, ill-defined Paria Plateau Syncline is quite low. No precise attitudes are available for rocks beneath most of House Rock Valley and the Paria Plateau, but these rocks do occupy a lowland area roughly between the Kaibab Plateau and Marble Plateau (Haynes and Hackman, 1978; Bush, 1983).

Northwest- and northeast-trending faults and grabens in the Marble Canyon area appear to be the most recent tectonic structures in the map area. Minor offset of Pleistocene alluvial deposits and Pleistocene volcanic deposits occur southeast of the map area (Billingsley and others, 2007). Fault offsets shown as a solid line between surficial and bedrock units on the map indicate a small fault scarp is present but there is no offset of surficial deposits.

The Colorado River and its tributaries became firmly established sometime in early Pliocene or early Miocene time, about 6 million years ago (Lucchitta, 1979; 1990; Ranney, 2005). Deepening of the Colorado River in Marble Canyon has gradually extended tributary drainages headward into House Rock Valley and Marble Plateau. Headward erosion continues from the Colorado River in Grand Canyon south of the map area into the Kaibab Plateau. This erosional process greatly enhances the widening of eastern Grand Canyon along the East Kaibab Monocline.

Gypsum dissolution within the Woods Ranch Member of the Toroweap Formation has resulted in several sinkholes on the Kaibab Plateau, indicated by a black triangle on the map. The sinkholes are likely Holocene and Pleistocene age because they disrupt local drainages and are commonly filled with fine-grained sediments. Deposits of gypsum in the Kaibab and Toroweap Formations are thickest along the west edge of the map area as reflected by the increase in sinkhole density in that area. There are sinkhole depressions in surficial units that are actively accumulating sediment and are shown on the map.

Circular bowl-shaped depressions in the Kaibab and Moenkopi Formations, characterized by inward-dipping strata are likely the surface expression of collapse-formed breccia pipe structures that originate from the dissolution of limestone in the Mississippian Redwall Limestone beneath House Rock Valley (Wenrich and Sutphin, 1989). The collapse features are indicated by a black dot on the map. Breccia pipes are indicated by a red dot and are characterized by having visible breccia within the collapse area as exposed along the Colorado River in Marble Canyon. Drilling is needed to confirm breccia pipe features within the collapse structures in House Rock Valley. Breccia pipes have the potential for concentrating uranium and other minerals at depth (Wenrich and Sutphin, 1989; Wenrich and Huntoon, 1989). Only circular collapse features that have inward-dipping strata are marked on the map as potential breccia pipes collapse structures at depth.

## **Mining Activity**

There are three small uranium prospects below the Vermilion Cliffs, the Sam Prospect, Jasper Prospect, and the Sun Valley Mine, all currently abandoned (Bush, 1983). The Jasper Prospect and Sun Valley Mine are located in the Shinarump Member of the Chinle Formation and the Sam Prospect is in the Petrified Forest Member of the Chinle Formation (fig. 1). Some production of uranium may have occurred from these prospects and mine. North of the map area, the El Pequito Mine, the Red Wing Mine, and the Lehneer Prospect are all located in the Shinarump Member of the Chinle Formation in Paria Canyon just west of Lees Ferry, Arizona (Phoenix, 1963; Haynes and Hackman, 1978; Bush, 1983).

There are currently no uranium mines or prospects developed within the east parcel of the segregated lands of House Rock Valley (fig. 1). There may be several uranium claims located on one or more of the collapse structures within this area.

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## DESCRIPTION OF MAP UNITS

### SURFICIAL DEPOSITS

Holocene and Pleistocene surficial deposits are differentiated from one another chiefly on differences in morphologic character, lithology, and physiographic position as illustrated on 1:24,000-scale color aerial photographs and field observations. These younger deposits are actively accumulating material or are only lightly eroded. Older alluvial and eolian deposits generally show extensive erosion, have greater topographic relief, and in some areas have developed a carbonate soil subhorizon. On the Paria Plateau and in upper House Rock Valley, extensive eolian sand sheet and dune deposits are relatively stabilized by vegetation during wet conditions. The deposits become unstable and mobile when disturbed by livestock or human activity. These deposits also reactivate during severe drought conditions or windy spring storms. Eolian and alluvial map contacts are provisional and arbitrary. Young surficial deposits are actively accumulating material and often subjected to modern wind or water erosion.

- Qaf Artificial fill and quarries (Holocene)**—Excavated alluvium and bedrock material removed from bar-pits and trenches to build livestock tanks, drainage diversion dams, landfills, roads, mines, and other construction projects (not all road and construction excavations are mapped)
- Qs Stream-channel deposits (Holocene)**—Poorly sorted, interbedded mud, silt, sand, pebbles, and gravel. Intertongue with or inset against young and intermediate alluvial fan (**Qa1**, **Qa2**), young and intermediate terrace-gravel (**Qg1**, **Qg2**), and upper part of valley alluvial (**Qv**) deposits; overlap or intertongue into flood-plain (**Qf**) and ponded sediment (**Qps**) deposits. Stream channels subject to high-energy flow and flash floods. Little or no vegetation in stream channels, except for a few tamarisk trees. Contact with adjacent alluvial or eolian deposits is approximate. Stream-channel deposits of Colorado River do not necessarily reflect stream-channel deposits of today due to extensive low-gradient channel changes caused by yearly fluctuation in stream levels and flooding. Thickness, 3 to 30 ft (1 to 9 m)
- Qf Flood-plain deposits (Holocene)**—Gray, brown, or light-red interbedded lenses of clay mud, silt, and sand; include some lenticular gravel. Partly consolidated by gypsum and calcite cement. Intertongue with or overlap stream-channel (**Qs**), valley alluvial (**Qv**), young terrace-gravel (**Qg1**), and young alluvial fan (**Qa1**) deposits. Subject to stream-channel erosion or overbank flooding in lateral and vertical sense. Similar to valley alluvial (**Qv**) deposits in small tributary drainage valleys. Subject to widespread and frequent overbank flooding along Colorado River and House Rock Wash. Support moderate growths of sagebrush, grass, tumble weed, desert shrubs, and tamarisk trees. Subject to temporary ponding and often mixed with ponded sediments (**Qps**) or young mixed alluvium and eolian (**Qae**) deposits along House Rock Wash. Thickness, 3 to 15 ft (1 to 4.5 m)
- Qes Young eolian sand sheet deposits (Holocene)**—House Rock Valley area: White, gray, and light-red, fine- to coarse-grained, windblown sand composed mainly of quartz, feldspar, and chert grains eroded from Jurassic, Triassic, and Permian rocks into drainages, primarily House Rock Wash, and transported by westerly winds. Form lumpy, ill-defined, geometric sand dunes or sand sheet deposits on alluvial fans northeast of House Rock Wash, mainly in upper House Rock Valley. Form extensive sand cover over gently sloping terrain on Paria Plateau. Commonly intertongue with young mixed alluvium and eolian (**Qae**) deposits. Support moderate growth of grass and small high-desert shrubs that stabilize eolian deposits in House Rock Valley; support grass, piñon pine, and juniper trees on Paria Plateau. Thickness, 1 to 30 ft (0.3 to 9 m)
- Qd Young sand sheet and dune deposits (Holocene)**—House Rock Valley area: Form climbing and falling dunes on steep landslide deposits in Vermilion Cliffs Natural Area and Paria Canyon-Vermilion Cliffs Wilderness below Paria Plateau (fig. 1). Support moderate growths of grass, Mormon tea, and sagebrush.
- Paria Plateau area: White to light-red, fine- to coarse-grained sand composed mainly of quartz and minor feldspar derived from nearby Navajo Sandstone. Intertongue locally with young eolian sand sheet (**Qes**) and young mixed alluvium and eolian (**Qae**) deposits. Include topographically controlled climbing and falling dunes, complex dunes,

and minor parabolic dunes that mantle gentle bedrock slopes and shallow valleys on Paria Plateau. Arbitrary and gradational contacts in the lateral and vertical sense with adjacent surficial deposits or bedrock outcrops. Sand is generally transported northeast by southwesterly winds actively eroding the Navajo Sandstone. Support moderate growth of grass, Mormon tea, sagebrush, and other high desert shrubs along with scattered piñon and juniper trees. Thickness, 3 to 80 ft (1 to 24 m)

- Qdp**     **Young parabolic dune deposits (Holocene)**—White, gray, light-red, fine- to coarse-grained, well-sorted, unconsolidated quartz sand arranged into individual parabolic dunes or poorly defined complex parabolic dune deposits. Pondered sandy sediment (**Qps**) deposits often form on upwind (southwest) side of parabolic dune complexes in House Rock Valley area. Bedrock or older sand accumulation is often exposed within interior of isolated parabolic dunes. Contact merges with adjacent dunes, sand sheets, alluvial deposits, and bedrock outcrops. Support little to sparse grassy vegetation. Thickness, 6 to 20 ft (2 to 6 m)
- Qg1**     **Young terrace-gravel deposits (Holocene)**—Light-brown, pale-red, and gray, well-sorted, interbedded clay, silt, sand, gravel, pebbles, cobbles, and some boulders. Partly consolidated with calcite and gypsum cement. Cobbles and boulders are composed of well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone. Subject to flash-flood erosion and overbank flooding. Locally overlaps or erodes into young alluvial fan (**Qa1**), flood-plain (**Qf**), and valley-fill (**Qv**) deposits. Often covered by or the source of young sand sheet and dune (**Qd**) deposits and young eolian sand sheet (**Qes**) deposits. Support light to no vegetation, mainly grass and a few desert shrubs. Contact with adjacent alluvial and eolian deposits is approximate. Form benches about 3 to 8 ft (1 to 2.5 m) above stream-channel (**Qs**) or flood-plain (**Qf**) deposits. Thickness, 4 to 12 ft (1.2 to 3.5 m)
- Qa1**     **Young alluvial fan deposits (Holocene)**—Reddish-gray to light-brown silt, sand, gravel, pebbles, cobbles, and boulders. Partly consolidated with calcite and gypsum cement. Pebbles, cobbles, and boulders are subangular to rounded limestone, chert, and sandstone clasts locally derived from local Permian and Mesozoic rocks west and north of House Rock Valley, and Paleozoic rocks within Marble Canyon. Unit is subject to extensive sheet-wash erosion, wind erosion, flash-flood debris flows, and minor arroyo erosion. Can be partially overlain by young sand sheet and dune (**Qd**), and young eolian sand sheet (**Qes**) deposits in upper House Rock Valley. Intertongue with upper part of valley-fill (**Qv**), young terrace-gravel (**Qg1**), and young mixed alluvium and eolian (**Qae**) deposits. Support sparse to minor growths of cactus and grass. Thickness 3 to 30 ft (1 to 9 m)
- Qg2**     **Intermediate terrace-gravel deposits (Holocene)**—Gray and brown silt, sand, gravel; includes lenses of small gravel or conglomerate clasts. Partly consolidated with calcite or gypsum cement. Lithologically similar to young terrace-gravel (**Qg1**) deposits. Siltstone and fine-grained sandstone matrix is mixed with subangular to rounded pebbles and boulders from local bedrock units. Form benches about 12 to 25 ft (3.5 to 7.5 m) above modern streambeds and about 6 to 20 ft (2 to 6 m) above young terrace-gravel (**Qg1**) deposits in upper reaches of tributary streams. Support growths of grass and a variety of desert shrubs. Subject to cut bank erosion by local streams. Locally intertongue with, overlain by, or inset into young and intermediate alluvial fan (**Qa1**, **Qa2**), valley-fill (**Qv**), young mixed alluvium and eolian (**Qae**), talus and rock-fall (**Qtr**), and landslide (**Ql**) deposits. Thickness, 6 to 25 ft (2 to 7.5 m)
- Qps**     **Pondered sediments (Holocene)**—Gray to red-brown clay, silt, sand, and gravel; partly consolidated by calcite and/or gypsum cement. Locally include small lenses of angular chert and limestone fragments or subrounded pebbles in sandy matrix. Similar to flood-plain (**Qf**) deposits but occupy man-made depressions, natural internal landslide depressions near Vermilion Cliffs, and areas with sand dune blockage along minor tributary drainages in upper House Rock Valley. Deposits on Paria Plateau commonly found in deflation hollows, depressions, or valleys in dune sand and sand sheet (**Qd**), eolian sand sheet and dune (**Qes**), and young mixed alluvium and eolian (**Qae**) deposits. In House Rock Valley, desiccation cracks develop during dry conditions in pondered areas

as a result of excessive clay content. Pondered areas on the Paria Plateau often develop parabolic dune complexes downwind (northeast) of excessive young eolian sand sheet (Qes) deposits. Thickness, 5 to 30 ft (1.5 to 9 m)

- Qae**     **Young mixed alluvium and eolian deposits (Holocene)**—Gray, light-red, fine- to coarse-grained interbedded sand, brown clay, silt, and lenses of pebbly or breccia gravel. Include angular white chert fragments locally derived from Permian strata on Kaibab Plateau in western part of House Rock Valley; white, gray, brown, and red chert fragments derived from Moenkopi, Chinle, Moenave, and Kayenta Formations below Vermilion Cliffs; white to gray chert fragments and concretionary sandstone pebbles derived from Navajo Sandstone on Paria Plateau. Deposit accumulates by a combination of alluvial and eolian processes resulting in a sequence of mixed interbedded mud, silt, sand, and gravel deposits; most common on Paria Plateau. Deposit subject to sheet wash erosion and arroyo cutting during wet conditions and windblown sand accumulation during dry conditions. Sediment commonly accumulates on broad sandy flatlands or on gently sloping alluvial fan topography. Unit often overlain by or interbedded with dune sand and sand sheet (Qd), and young eolian sand sheet (Qes) deposits. Support light to moderate growth of grass, cactus, sagebrush, and other desert shrubs. Thickness, 3 to 25 ft (1 to 7.5 m)
- Qa2**     **Intermediate alluvial fan deposits (Holocene and Pleistocene(?))**—Lithologically similar to young alluvial fan (Qa1) deposits but show some dissection. Partly cemented by calcite, gypsum, and clay. Surface can be eroded by arroyos as much as 3 to 10 ft (1 to 3 m) deep. Unit is typically covered by young sand sheet and dune (Qd) deposits in upper House Rock Valley or young eolian sand sheet (Qes) deposits along Vermilion Cliffs and partly overlain by young alluvial fan (Qa1) deposits at distal ends. Intertongue with or overlain by valley-fill (Qv), talus and rock-fall (Qtr), and young and intermediate terrace-gravel (Qg1, Qg2) deposits in upper House Rock Valley. Support light to moderate growths of grass, sagebrush, and cactus. Thickness, 6 to 50 ft (2 to 15 m)
- Qv**     **Valley alluvial deposits (Holocene and Pleistocene(?))**—Gray and light-brown silt, sand, and lenses of gravel; partly consolidated by gypsum and calcite. Include occasional rounded clasts of limestone, sandstone, and subrounded to angular chert; also rounded chert or quartz pebbles derived from Shinarump Member of the Chinle Formation below Vermilion Cliffs. Intertongue with or overlain by young and intermediate alluvial fan (Qa1, Qa2) deposits and young and intermediate terrace-gravel (Qg1, Qg2) deposits. Commonly reflects low energy, low-gradient, and sediment accumulations in shallow drainages. Subject to sheet wash flooding. Thickness, 3 to 30 ft (1 to 9 m)
- Qtr**     **Talus and rock-fall deposits (Holocene and Pleistocene(?))**—In Marble Canyon: gray to yellowish-red silt, sand, and breccia gravel mixed with abundant small to large angular rocks and boulders of limestone, sandstone, and chert derived from local steep walled areas of Paleozoic strata; partly cemented by calcite and gypsum. Along Vermilion Cliffs: red to yellow, silt, sand, and breccia gravel mixed with angular rocks and boulders of light-red or white sandstone and red to dark-red siltstone; partly cemented by calcite. Unit often associated with landslide (Ql) deposits. Unit commonly grades downslope into young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) deposits or young, intermediate, and old terrace-gravel (Qg1, Qg2, Qg3) deposits. Thickness, 5 to 45 ft (1.5 to 14 m)
- Qg3**     **Old terrace-gravel deposits (Holocene and Pleistocene)**—Gray and light-brown, clay, silt, sand, gravel, cobbles and boulders partly consolidated by clay, calcite, and gypsum cement; poorly sorted. Include abundant rounded and well-rounded clasts of quartzite, quartz, chert, sandstone, and limestone. Form isolated terrace deposits as much as 40 ft (12 m) above tributary drainages below Vermilion Cliffs near Cliff Dwellers Lodge and at one locality along South Canyon in House Rock Valley. Thickness, 6 to 20 ft (2 to 6 m)
- Qa3**     **Old alluvial fan deposits (Holocene and Pleistocene)**—Below Vermilion Cliffs: Light-brown to light-red, unsorted silt, sand, gravel, mixed with brecciated and subrounded pebbles and cobbles of red sandstone and gray to red chert; partly consolidated by calcite cement. Unit partly overlain by young eolian sand sheet (Qes) and young mixed alluvium and

eolian (Qae) deposits. Include large rounded or angular boulders, small cobbles, and pebbles of local sedimentary rocks derived from nearby talus and rock-fall (Qtr) and landslide (Ql) deposits. Support sparse growths of grass, cactus, and various desert shrubs.

In western House Rock Valley: Gray to light-brown, unsorted silt, sand, and gravel mixed with brecciated and subrounded pebbles and cobbles of gray limestone and chert; partly consolidated by calcite and gypsum cement. Include large debris flow cobbles and boulders of Permian strata derived from Kaibab Plateau area. Support light growths of grass, cactus, high desert shrubs and bushes. Thickness, 5 to 25 ft (1.5 to 7.5 m)

- Ql **Landslide deposits (Holocene and Pleistocene)**—Unconsolidated to partly consolidated masses of angular unsorted rock debris. Include large detached stratified slump blocks of Mesozoic strata that have rotated backward and slid downslope against or below the parent outcrop as loose mass of broken rock fragments and deformed strata; often associated with talus and rock-fall (Qtr) deposits adjacent to and below landslide masses. Include individual car- and house-size boulders. Often covered by young sand sheet and dune (Qd) deposits that form falling or climbing dunes on steep slopes near base of Vermilion Cliffs, or lightly covered by young eolian sand sheet (Qes) deposits. Gradational and arbitrary contact with young, intermediate, and old alluvial fan (Qa1, Qa2, and Qa3) as well as young and intermediate terrace-gravel (Qg1, Qg2) deposits. Subject to extensive sheet wash erosion, flash-flood debris flows, rock falls, and arroyo erosion. Lower landslide deposits form an extended toe or debris tongues over the Chinle and Moenkopi Formations and onto the Kaibab Formation. Thickness, 10 to 300 ft (3 to 91 m)
- Qa4 **Older alluvial fan deposits (Pleistocene)**—Gray, sandy, gravelly fluvial debris-flow deposits; once part of a more extensive alluvial fan deposit into House Rock Valley along base of the Kaibab Plateau below Little Mountain drainages. Include breccia clasts and boulders derived from the Hermit Formation, Coconino Sandstone, Toroweap Formation, Kaibab Formation, and Moenkopi Formation from the Kaibab Plateau. Unit is extensively eroded and gullied; eroded material is redeposited in adjacent younger alluvial fans. Form a protective cap-rock surface over softer strata of Moenkopi Formation. Support light to moderate growths of grass, cactus, and various high desert shrubs and bushes. Thickness, 10 to 25 ft (3 to 7.5 m)
- Qg4 **Oldest terrace-gavel deposits (Pleistocene)**—Gray and light-brown clay, silt, sand, gravel, and well-rounded pebbles and cobbles; poorly sorted and partly consolidated by calcrete soil in top 1 m (3 ft). Contain subrounded fragments of petrified wood and well-rounded clasts of quartzite, chert, sandstone, limestone, and volcanic clasts that appear to be derived from Colorado or New Mexico. Deposits are typically within a quarter mile of modern Colorado River along Marble Canyon. Support minor growths of grass and low desert shrubs. Thickness, 2 to 15 ft (1 to 4.5 m)

## SEDIMENTARY ROCKS

**Glen Canyon Group**—The Glen Canyon Group (Lower Jurassic) includes, in descending order, the Navajo Sandstone, Kayenta Formation, Springdale Sandstone Member of the Kayenta Formation, and the Moenave Formation. The lower boundary of the Glen Canyon Group unconformably overlies the Triassic Owl Rock Member of the Chinle Formation forming the boundary between Jurassic and Triassic units.

Approximately 7 miles (11 km) north of the map area, the upper boundary of the Glen Canyon Group forms the J-2 unconformity between the Navajo Sandstone and Page Sandstone, or the Navajo Sandstone and the Carmel Formation where the Page Sandstone is missing (Doelling and others, 2000). The Carmel Formation is part of the overlying San Rafael Group above the J-2 unconformity

- Jn **Navajo Sandstone (Lower Jurassic)**—Red, white, and tan, cliff-forming, high-angle crossbedded, fine- to medium-grained, well-sorted sandstone. Quartz grains are frosted. Includes massive horizontal or planar bedding between crossbed sets as much as 35 ft (11 m) thick. Includes thin lenses or discontinuous beds of gray siliceous limestone,

dolomite, or dark-red sandy siliceous mudstone and brown chert that weather out as resistant ledges forming flat-topped ridges or hills on eroded surface of Paria Plateau. Dip direction of crossbed sets indicate paleowinds from the north and northwest. Gradational and arbitrary contact with underlying Kayenta Formation at lowest white or red massive sandstone cliff of Navajo Sandstone. Unit gradually thins east of Marble Canyon and thickens west and northwest of map area. Thickness, 1,675 to 1,850 ft (510 to 564 m)

**Kayenta Formation (Lower Jurassic)**—Includes in descending order, the Kayenta

Formation (Jk) and Springdale Sandstone Member (Jks)

Jk

**Kayenta Formation (Lower Jurassic)**—Includes an upper slope- and ledge-forming sequence of light-purple siltstone and red sandstone unit and a lower cliff-forming dark-orange-brown sandstone of the Springdale Sandstone Member. The Springdale Sandstone was originally described by Gregory (1950) as part of the Chinle Formation and redefined as an upper member of the underlying Moenave Formation (Averitt and others, 1955; Harshbarger and others, 1958; Stewart and others, 1972; Sargent and Philpott, 1987; Billingsley and others, 2004). More recently, the Springdale Sandstone has been reassigned to the basal part of the Kayenta Formation (Biek and others, 2007) on the basis of paleontological data and a prominent Jurassic unconformity at the base of the Springdale Sandstone (Blakey, 1994; Marzolf, 1991; Lucas and Tanner, 2006; Tanner and Lucas, 2007; Biek and others, 2007). Upper slope-forming unit: Purple, lavender, and light-red fluvial, crossbedded, fine-grained mudstone, siltstone, silty sandstone, and crossbedded sandstone near Cliff Dwellers Lodge that undergoes a northward facies change to mostly cliff- and ledge-forming red-brown siltstone sandstone along Vermilion Cliffs west of Marble Canyon, Arizona. Age of unit was determined by Peterson and Pipiringos (1979) and Biek and others (2007). The Kayenta Formation is often covered by massive landslide and talus and rock fall deposits. Unconformable contact with underlying Springdale Sandstone Member. Thickness, 120 to 200 ft (37 to 60 m)

Jks

**Springdale Sandstone Member (Lower Jurassic)**—Light-red to reddish-brown and dark-red, cliff-forming, thin- to thick-bedded sandstone and interbedded thin siltstone and mudstone. Includes low-angle trough crossbedded sets of fluvial conglomeratic sandstone lenses that contain dark-red mudstone and siltstone rip-up clasts and poorly preserved petrified and carbonized fossil plant remains (Peterson and Pipiringos, 1979; Biek and others, 2007). Crossbeds are separated by thin-bedded to laminated dark-red siltstone and mudstone that locally contain mudstone pellet inclusions. Unconformable contact with underlying Moenave Formation. Upper light-red, fine-grained, crossbedded sandstone fills local channel depressions within unconformity near top of Springdale Sandstone that may be southern extent of Wingate Sandstone in Utah (Biek and others, 2007). Thickness, 180 to 225 ft (55 to 68 m)

Jm

**Moenave Formation (Lower Jurassic)**—Includes only the Dinosaur Canyon Member as redefined by Blakey (1994); Marzolf (1991); Lucas and Tanner (2006); Tanner and Lucas (2007); Biek and others (2007). Herein mapped as the Moenave Formation. Age of unit was determined by Peterson and Pipiringos (1979) and Biek and others (2007). Reddish-brown, slope- and ledge-forming, thin- flat-bedded and crossbedded, fine- to coarse-grained fluvial siltstone and silty sandstone. Unconformable contact with underlying Owl Rock Member of Chinle Formation known as the J-O unconformity separating Triassic rocks from overlying Jurassic rocks. Unit commonly covered by landslide (Ql) or talus and rock-fall (Qtr) deposits. Thickness, 90 to 220 ft (27 to 67 m)

**Chinle Formation (Upper Triassic)**—Includes, in descending order, the Owl Rock Member, Petrified Forest Member, and the Shinarump Member (Repenning and others, 1969)

Tco

**Owl Rock Member (Upper Triassic)**—Grayish-red and light-purple, slope- and ledge-forming, nodular siliceous limestone interbedded with purple, light-blue, and light-red calcareous siltstone and sandstone. Limestone beds are gray, cherty, lenticular, silty, irregularly bedded, .05 to 1 ft (0.1 to 0.5 m) thick. Unit contains abundant mud pellets, silicified clay, and concretionary chert nodules. Gradually thins northward to Lees Ferry, Arizona; gradually thickens southeast of the map area. Unconformable contact between Owl Rock Member and overlying Moenave Formation marked by distinct lithology and

	color change. Gradational and arbitrary contact with underlying Petrified Forest Member placed at lowest limestone bed. Thickness, 150 to 200 ft (45 to 60 m)
‡cp	<b>Petrified Forest Member (Upper Triassic)</b> —Purple, blue, light-red, reddish-purple, grayish-blue, slope-forming mudstone and siltstone and interbedded white, coarse-grained lenticular sandstone. Includes large lenticular erosional channel structures and large-scale, low-angle, trough siltstone crossbeds. Petrified logs and wood fragments common in white or yellowish-white sandstone of lower part, which may be within upper part of Shinarump Member of the Chinle Formation. Gradational and arbitrary contact with underlying Shinarump Member marked at lithologic and topographic change from slope-forming multicolored mudstone of Petrified Forest Member to tan cliffs as well as purple and white slopes of coarse-grained sandstone of Shinarump Member. Weathers into rounded hills or slopes with a rough, puffy, popcorn textural surface due to swelling of clay content when wet. Sandstones are uranium and copper bearing in some places and in others contain traces of gold and mercury (Bush, 1983). Thickness, 600 to 625 ft (182 to 190 m)
‡cs	<b>Shinarump Member (Upper Triassic)</b> —White, light-brown, and yellowish-pink, cliff- and slope-forming coarse-grained sandstone and conglomeratic sandstone. Includes white low-angle crossbedded sandstone interbedded with slope-forming, poorly sorted, purple, light-red, and blue siltstone and mudstone where tan, cliff-forming conglomeratic sandstone is absent. Lithology is highly variable but is relatively homogeneous from a regional viewpoint consisting of about 75 percent sandstone, 20 percent conglomerate, and 5 percent mudstone. Pebbles are well rounded brown to black siliceous composition and light-colored quartz composition. Petrified logs and wood fragments are common and scattered throughout unit. Forms unconformable contact with underlying red siltstone and sandstone of Moenkopi Formation. Unit is thickest north of Cliff Dwellers Lodge along U.S. Highway 89A; thins southward along U.S. Highway 89A and Vermilion Cliffs near House Rock Valley area. Contains traces of uranium, copper, gold, and mercury minerals (Bush, 1983). Thickness, 0 to 180 ft (0 to 55 m)
	<b>Moenkopi Formation (Middle(?) and Lower Triassic)</b> —Includes, in descending order, the upper red member, Shnabkaib Member and lower members, undivided as defined by Stewart and others (1972)
‡mu	<b>Upper red member (Middle(?) and Lower Triassic)</b> —Reddish-brown alternating sequence of slope-forming claystone, siltstone, and sandstone. Includes large- to medium-scale trough crossbedding, abundant cusp-type ripple marks, interbedded thin limestone, lenses of conglomeratic sandstone, and nodules, veins, and thin beds of gypsum. Gradational contact with underlying Shnabkaib Member. Pre-Chinle Formation Triassic erosion has removed upper red member from Vermilion Cliffs Lodge to Lees Ferry, Arizona, and Shnabkaib Member is overlain by Shinarump Member of the Chinle Formation. Thickness, 0 to 120 ft (0 to 37)
‡ms	<b>Shnabkaib Member (Lower Triassic)</b> —Yellowish-white, light-brown, and dark-red-brown cliff-forming, crossbedded, fine-grained, calcareous and gypsiferous siltstone and coarse-grained sandstone. Unit is equivalent to lower massive sandstone member of the Moenkopi Formation south of map area (Billingsley and others, 2007) as defined by McKee (1954). Unit undergoes southwest to northeast facies change from white marine calcareous gypsiferous siltstone south of Cliff Dwellers Lodge to brown and dark red-brown, cliff-forming calcareous sandstone west of Vermilion Cliffs Lodge. Unit is gradually removed by Triassic erosion from Marble Canyon, Arizona north. Gradational contact with underlying lower members marked at base of white gypsiferous cliff or brown to dark-brown sandstone cliff of Shnabkaib Member, or base of Triassic channel unconformity filled with brown conglomeratic sandstone of Shinarump Member of Chinle Formation. Thickness, 0 to 100 ft (0 to 30 m)
‡mlm	<b>Lower members, undivided (Lower Triassic)</b> —Includes, in descending order, middle red member, Virgin Limestone Member, and lower red member in southeastern three quarters of map area. Basal Timpoweap Member of the Moenkopi Formation is present but too thin and limited in extent to show at map scale and is included as part of the lower red member of the Moenkopi Formation, undivided. Timpoweap Member is composed of



conglomeratic limestone or calcareous sandstone with small white, angular chert pebbles and fragments derived from Early Triassic erosion of the Kaibab Formation. Occupies shallow depressions and channels eroded into underlying Harrisburg Member of the Kaibab Formation in western and southern parts of map area.

The Moenkopi Formation is mostly eroded from or covered by surficial deposits in the House Rock Valley and Marble Canyon areas. The lower members, undivided, are present as isolated hills covered by older alluvial fan (Qa4) deposits below the East Kaibab Monocline in western House Rock Valley, and these members form a continuous outcrop along the base of the Vermilion Cliffs west and north of U.S. Highway 89A. Unit is distinguished from underlying red siltstone and sandstone beds of Harrisburg Member of the Kaibab Formation by its darker red color, thin-bedded, platy, coarse-grained conglomeratic sandstone beds. Forms unconformable contact with underlying Harrisburg Member of the Kaibab Formation representing the regional Permian/Triassic unconformity. Overall thickness before Cenozoic erosion, about 500 ft (152 m) along west edge of map area. Unit thins east to about 460 ft (140 m) southwest of Cliff

Dwellers Lodge, Arizona, and north to about 320 ft (97 m) near Marble Canyon, Arizona

**Kaibab Formation (Cisuralian)**—Includes, in descending order, the Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991)

**Pkh Harrisburg Member (Cisuralian)**—Reddish-gray and brownish-gray, ledge- and slope-forming gypsiferous siltstone, calcareous sandstone, and thin-bedded sandy limestone. Includes white, low-angle crossbedded calcareous sandstone containing molluscan fossils at top of unit along southern and western edge of House Rock Valley; elsewhere, upper part is primarily sandy, cherty limestone. Forms bedrock surface in House Rock Valley and the rim of Marble Canyon. Contact with underlying Fossil Mountain Member is gradational and arbitrarily marked at topographic break between grayish-white, slope- and ledge-forming sandy limestone and sandstone sequence of Harrisburg Member and underlying gray, cliff-forming, gray to light-brown, thick-bedded cherty limestone and sandy limestone of Fossil Mountain Member. Unit gradually thins west to east and undergoes a shoreward (eastward) facies change from mostly marine limestone to mostly sandy marine limestone and calcareous sandstone. Thickness, 80 to 120 ft (25 to 37 m)

**Pkf Fossil Mountain Member (Cisuralian)**—Light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (1 to 6 ft [0.3 to 2 m]), fossiliferous, cherty, sandy limestone and dolomite. Weathers dark-gray and often stained by black magnesium oxide. Includes abundant gray and white chert nodules and white chert breccia beds. Chert makes up about 25 to 30 percent of Fossil Mountain Member. Some chert nodules show concentric black and white bands or contain fossil sponges. White, cliff-forming chert breccia beds 4 to 10 ft (1 to 3 m) thick commonly form uppermost part of Fossil Mountain Member that help establish the contact between Harrisburg and Fossil Mountain Members. Unit gradually thins eastward and undergoes a shoreward (eastward) facies change from limestone, dolomite, and sandy limestone to calcareous sandstone and sandy limestone similar in texture, composition, and appearance to overlying Harrisburg Member. Commonly forms a cliff below slopes and ledges of the Harrisburg Member at the rim of Marble Canyon. Unconformable contact with underlying Toroweap Formation attributed to dissolution and erosion of gypsiferous siltstone beds of the Toroweap; average erosional relief, about 10 ft (3 m). Unit gradually thins east and southeast in map area. Thickness, 160 to 230 ft (48 to 70 m)

**Pt Toroweap Formation, undivided (Cisuralian)**—Includes, in descending order, the Woods Ranch (Ptw), Brady Canyon (Ptb), and Seligman (Pts) Members, as defined by Sorauf and Billingsley (1991). All three members are present in parts of western Marble Canyon and beneath House Rock Valley but undergo a rapid shoreward (eastward) facies change from general cliff and slope units west of Colorado River to an all-cliff unit east of Marble Canyon. Unit gradually thins east and southeast of Marble Canyon and gradually thickens west of House Rock Valley (Billingsley and Workman, 2000; Billingsley and Wellmeyer, 2001). Individual Members of the Toroweap Formation are mapped in canyons cut into the Kaibab Plateau west and northwest of House Rock Valley

	(Billingsley and others, 2001; Billingsley and Wellmeyer, 2001; Billingsley and Hampton, 2001; Billingsley and others, 2007). Thickness, 180 to 220 ft (60 to 76 m)
Ptw	<b>Woods Ranch Member (Cisuralian)</b> —Gray and light-red, slope-forming gypsiferous siltstone, gray gypsum, and gray sandstone interbedded with gray, thin-bedded limestone. Weathers to reddish-gray slope. Bedding locally distorted owing to dissolution of gypsum and gypsiferous siltstone. Unit undergoes shoreward (eastward) facies change to mostly brown, cliff-forming calcareous sandstone and dolomite that weathers dark-brown. Contact with underlying Brady Canyon Member west of House Rock Valley is gradational and marked at lithologic and topographic break between slope-forming gypsiferous siltstone and sandstone of Woods Ranch Member and cliff-forming limestone of Brady Canyon Member at Kaibab Plateau and in western parts of Marble Canyon; becomes indistinguishable from underlying Seligman and Brady Canyon Members in eastern part of Marble Canyon. Thickness, 140 to 200 ft (43 to 60 m)
Ptb	<b>Brady Canyon Member (Cisuralian)</b> —Yellowish-gray, gray to brown, cliff-forming, thin- to medium-bedded (1 to 6 ft [0.05 to 2 m]), fine- to coarse-grained limestone and dolomitic sandy limestone. Weathers light-gray. Contains white and gray chert nodules and lenses that make up less than 5 percent of unit. Contains brachiopods, crinoids, and bryozoan fossils in Kaibab Plateau area. Gradational contact with underlying Seligman Member arbitrarily marked at base of limestone cliff at Kaibab Plateau and in parts of western Marble Canyon. Unit too thin to show at map scale in Marble Canyon. Becomes indistinguishable from other members of Toroweap Formation in eastern part of Marble Canyon where it forms a continuous cliff with overlying Kaibab Formation and underlying Coconino Sandstone. Unit gradually thins east and south of map area and thickens west of House Rock Valley. Thickness, 10 to 30 ft (3 to 9 m)
Pts	<b>Seligman Member (Cisuralian)</b> —Yellowish-gray, gray, light-purple, and yellowish-red, ledge- and slope-forming, thin-bedded dolomite, sandstone, gypsum, and calcareous sandstone. Forms recessive slope between overlying cliff-forming Brady Canyon Member of the Toroweap Formation and underlying cliff-forming Coconino Sandstone at Kaibab Plateau and in western part of Marble Canyon (but unit is too thin to show in Marble Canyon area). Basal part includes yellow, fine- to medium-grained, thin-bedded, low- to high-angle cross- and planar-bedded sandstone lenses of the Coconino Sandstone (Fisher, 1961; Schleh, 1966; Rawson and Turner, 1974; and Billingsley and others, 2000; 2006). Unit undergoes gradual easterly shoreward facies change with overlying Brady Canyon and Woods Ranch Members making all three members indistinguishable from each other east of Colorado River where mapped collectively as Toroweap Formation. Sharp planar contact with underlying white, cliff-forming Coconino Sandstone. Thickness, 10 to 20 ft (3 to 6 m)
Pc	<b>Coconino Sandstone (Cisuralian)</b> —Tan to white, cliff-forming, fine-grained, well-sorted, high-angle crossbedded quartz sandstone. Crossbed sets are 6 to 15 ft (3 to 4.5 m) thick. Locally includes large and small fossil amphibian track ways and low-relief wind ripple marks on planar surfaces. Unconformable, planar erosional contact with underlying Hermit Formation with relief generally less than 3 ft (1 m) but locally as much as 8 ft (2.5 m). Contact is marked by distinct color and topographic change between white, cliff-forming Coconino Sandstone and underlying dark-red, slope-forming Hermit Formation. Unit rapidly pinches out northwest of House Rock Valley and northward under Paria Plateau and thickens southeast and south of House Rock Valley. Thickness, 50 to 400 ft (15 to 122 m)
Ph	<b>Hermit Formation (Cisuralian)</b> —Red, slope-forming, fine-grained, thin- to medium-bedded siltstone and sandstone. Siltstone beds throughout unit are dark red and crumbly and fill widespread, shallow erosional channels that form recesses between thicker sandstone beds. Channel-fill deposits locally contain poorly preserved plant fossils in lower part of unit in Grand Canyon area. Unconformably overlies Esplanade Sandstone with erosional relief generally less than 10 ft (3 m). Unit thins gradually southeast of Marble Canyon and thickens west of map area. Thickness, 520 to 640 ft (158 to 195 m)

**Supai Group (Cisuralian, Upper, Middle, and Lower Pennsylvanian, and Upper**

	<p><b>Mississippian)</b>—Includes in descending order, the Esplanade Sandstone; Wescogame Formation, Manakacha Formation, and Watahomigi Formation, undivided, as defined by McKee (1982)</p>
Pe	<p><b>Esplanade Sandstone (Cisuralian)</b>—Light-red and pinkish-gray, cliff-forming, fine- to medium-grained, medium- to thick-bedded (3 to 10 ft [1 to 3 m]), well-sorted calcareous sandstone. Includes interbedded dark-red, thin-bedded, crumbly, recessive and slope-forming siltstone beds in upper and lower part. Crossbeds are small- to medium-scale, planar, low-angle and high-angle sets. Unconformable contact with underlying Pennsylvanian and Upper Mississippian rocks marked by erosion channels as much as 15 ft (4.5 m) deep filled with conglomerate that is well displayed in North Canyon in Marble Canyon area. Thickness, 350 to 400 ft (107 to 122 m)</p>
IPMs	<p><b>Lower Supai Group, undivided (Upper, Middle, and Lower Pennsylvanian and Upper Mississippian)</b>—Includes, in descending order, Wescogame, Manakacha, and Watahomigi Formations as defined by McKee (1982). Individual formations are difficult to identify in the field and are shown as one map unit</p> <p><b>Wescogame Formation (Upper Pennsylvanian)</b>—Light-red, pale-yellow, and light-gray upper slope unit and lower cliff unit. Upper slope consists of dark-red, fine-grained siltstone and mudstone interbedded with light-red, coarse-grained, calcareous sandstone and dolomitic sandstone, siltstone, mudstone, and conglomerate. Lower cliff consists of light-red to gray, high-angle, large- and medium-scale, tabular-planar, crossbedded sandstone and calcareous sandstone sets as much as 20 ft (6 m) thick. Unconformable contact with underlying Manakacha Formation marked by erosion channels as much as 3 ft (1 m) deep in Marble Canyon. Channels commonly filled with limestone/chert conglomerate. Thickness, 110 to 130 ft (34 to 40 m)</p> <p><b>Manakacha Formation (Middle Pennsylvanian)</b>—Light-red, white, and gray upper slope and ledges of sandstone, calcareous sandstone, dark-red siltstone, and thin gray calcareous sandstone. Upper slope consists mainly of shaley siltstone and mudstone with minor interbedded, thin-bedded sandstone. Carbonate content of upper slope increases southwestward to form numerous ledge-forming, thin- and medium-bedded limestone beds in Grand Canyon. Lower cliff is dominated by reddish-gray, medium- to thick-bedded, crossbedded calcareous sandstone as well as sandy limestone. Carbonate content increases west of map area where numerous gray limestone ledges are present (McKee, 1982). Unconformable contact between the Manakacha Formation and underlying Watahomigi Formation marked at base of lower red sandstone cliff of Manakacha; erosional relief generally less than 3 ft (1 m). Thickness, 175 ft (53 m)</p> <p><b>Watahomigi Formation (Lower Pennsylvanian and Upper Mississippian)</b>—Gray and purple, slope-forming limestone, siltstone, mudstone, and some conglomerate. Lower limestone beds contain red chert lenses and nodules. Includes alternating gray, thin-bedded cherty limestone ledges interbedded with purplish-gray siltstone and mudstone in upper part. Lower slope consists mainly of purplish-red mudstone and siltstone, interbedded with thin-bedded, aphanitic to granular limestone with red chert veins and nodules. Conodonts in lower thin limestone beds west of map area are Late Mississippian age (Martin and Barrick, 1999). Unit includes purple siltstone and gray limestone interbedded with reddish conglomeratic sandstone that fills small erosion channels cut into either the Surprise Canyon Formation (Ms) or Redwall Limestone (Mr). Supai Group gradually thins eastward and gradually thickens west of map area. Thickness, 100 to 120 ft (30 to 37 m)</p>
Ms	<p><b>Surprise Canyon Formation (Upper Mississippian)</b>—Dark-reddish-brown, massive to thin-bedded, poorly sorted siltstone, sandstone, thin-bedded gray limestone and dolomite, and conglomerate gray and white subrounded chert clasts derived from the Redwall Limestone and supported in dark-red or black sandstone matrix. Unit is limited to deposits within shallow paleovalleys and karst caves eroded into top half of underlying Redwall Limestone (Billingsley and Beus, 1999). Unit is likely present in subsurface of southern part of map area. Sandstone and siltstone beds contain plant and bone fossils, mudcracks, and ripple marks. Thickness, 0 to 40 ft (0 to 12 m)</p>
Mr	<p><b>Redwall Limestone, undivided (Upper and Lower Mississippian)</b>—Includes, in descending</p>

order, Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, as defined by McKee (1963) and McKee and Gutschick (1969). Members are not shown at map scale because of the sheer cliff topography of the Redwall Limestone. Unit overall is light-gray to dark-gray, cliff-forming, thin- to thick-bedded, fine- to coarse-grained, fossiliferous limestone and dolomite. Includes thin-bedded gray and white chert beds, lenses, and nodules. Unit gradually thins eastward and thickens west of Marble Canyon area and is an important subsurface aquifer because of solution-eroded caverns and linear caves along joint and fracture systems that transport water through the unit. Thickness, 500 to 550 ft (152 to 167 m)

**Horseshoe Mesa Member**—Light-olive-gray, ledge- and cliff-forming, thin-bedded, fine-grained limestone. Weathers to receding ledges. Gradational and disconformable contact with underlying massive-bedded limestone of Mooney Falls Member marked by thin-bedded, platy limestone beds of Horseshoe Mesa Member that form recesses about 3 to 9 ft (1 to 3 m) thick near top of cliff. Fossils are locally common. Includes distinctive ripple-laminated limestone and oolitic limestone beds and some chert lenses. Unit locally absent where removed by Late Mississippian paleovalley erosion. Thickness, 50 to 100 ft (15 to 30 m)

**Mooney Falls Member**—Light-gray, cliff-forming, fine- to coarse-grained, thick-bedded to very thick-bedded [4 to 20 ft (1 to 6 m)], fossiliferous limestone. Limestone weathers dark gray; chert beds weather black. Includes dark-gray dolomite beds; oolitic limestone and chert beds restricted to upper part. Karst caves within upper part often contain red sandstone and siltstone deposits of the Surprise Canyon Formation in Marble Canyon area. Disconformable contact with the underlying Thunder Springs Member marked by lithology change between massive-bedded, gray limestones of Mooney Falls Member and thin-bedded, dark-gray to brown dolomite and white chert beds of Thunder Springs Member. Thickness, 300 ft (75 m)

**Thunder Springs Member**—Member is alternating beds of gray, cliff-forming, fossiliferous, thin-bedded limestone and brownish-gray, cliff-forming, thin-bedded [1 to 5 in (2 to 12 cm)], finely crystalline dolomite and fine- to coarse-grained limestone interbedded with thin beds of white chert. Locally includes large-scale crossbedding and irregularly folded beds. Nautiloid fossils are common in upper 10 ft (3 m) of unit. The disconformable planar contact with the underlying Whitmore Wash Member is distinguished by a distinct lack of white chert in Whitmore Wash Member. Thickness, 100 ft (30 m)

**Whitmore Wash Member**—Yellowish-gray and brownish-gray, cliff-forming, thick-bedded, fine-grained dolomite. Weathers dark gray. Unconformable contact with underlying Devonian Temple Butte Formation or Cambrian Muav Limestone marked by low relief (about 5 to 10 ft [2 to 3 m]) erosion channels just south of map edge in Marble Canyon. Unit mostly overlies flat ledges of light-gray to greenish-gray, thin-bedded limestone of Cambrian Muav Limestone; locally overlies reddish-purple mudstone and dark-gray contorted limestone beds of channel-fill deposits of Temple Butte Formation within Marble Canyon just south of map area. Thickness, 80 ft (25 m)

#### **SUBSURFACE PALEOZOIC ROCKS OF HOUSE ROCK VALLEY**

Cambrian and Devonian rocks do exist beneath the Mississippian Redwall Limestone in the map area based on exposures in Marble Canyon and Grand Canyon just south of the map area as shown by Huntoon and others (1996) and Timmons and others (2007).

## References

- Akers, J.P., Cooley, M.E., and Repenning, C.A., 1958, Moenkopi and Chinle Formations of Black Mesa Basin and adjacent areas, *in* Guidebook of the Black Mesa Basin, northeastern Arizona, 9<sup>th</sup> field conference: New Mexico Geological Society, p. 88-94.
- Averitt, P., Wilson, R.F., Detterman, J.S., Harshbarger, J.W., and Repenning, C.A.H., 1955, Revisions in correlation and nomenclature of Triassic and Jurassic formations in southwestern Utah and northern Arizona: Bulletin of the American Association of Petroleum Geologists, v. 39, no. 12, p. 2,515-2,524.
- Biek, R.F., Rowley, P.D., Hacker, D.B., Hayden, J.M., Willis, G.C., Hintze, L.F., Anderson, R.E., and Brown, K.D., 2007, Interim geologic map of the St. George 30' x 60' quadrangle and the east part of the Clover Mountains 30' x 60' quadrangle, Washington and Iron Counties, Utah: Utah Geological Survey, Utah Department of Natural Resources, Open-File Report 478, scale 1:100,000, 70 p.
- Billingsley, G.H., and Beus, S.S., 1999, Geology of the Surprise Canyon Formation of the Grand Canyon, Arizona: Museum of Northern Arizona Bulletin 61, Museum of Northern Arizona Press, 254 p, 9 pls.
- Billingsley, G.H., and Breed, W.J., 1973, The origin of the barbed tributaries in Marble Canyon, Arizona: Plateau, v. 45, no. 3, p. 128-132.
- Billingsley, G.H., and Hampton, H.M., 2001, Geologic map of the House Rock Spring quadrangle, Coconino County, northern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2367, scale 1:24,000, 9 p. [<http://pubs.usgs.gov/mf/2001/2367/>].
- Billingsley, G.H., Harr, Michelle, and Wellmeyer, J.L., 2000, Geologic map of the Upper Parashant Canyon and vicinity, northern Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2343, scale 1:31,680, 27 p. [<http://pubs.usgs.gov/mf/2000/2343/>]
- Billingsley, G.H., Priest, S.S., and Felger, T.J., 2004, Geologic map of Pipe Spring National Monument and the western Paiute-Kaibab Indian Reservation, Mohave County, Arizona: U.S. Geological Survey Scientific Investigations Map 2863, scale 1:31,680, 22 p. [<http://pubs.usgs.gov/sim/2004/2863/>]
- Billingsley, G.H., Priest, S.S., and Felger, T.J., 2007, Geologic map of the Cameron 30' x 60' quadrangle, Coconino County, northern Arizona: U.S. Geological Survey Scientific Investigations Map 2977, scale 1:100,000, 33 p. [<http://pubs.usgs.gov/sim/2007/2977/>]
- Billingsley, G.H., Priest, S.S., and Felger, T.L., 2008, Geologic map of the Fredonia 30' x 60' quadrangle, Mohave and Coconino Counties, northwestern Arizona: U.S. geological Survey Scientific Investigations Map 3035, scale 1:100,000, p. [<http://pubs.usgs.gov/sim/2008/3035/>]
- Billingsley, G.H., and Wellmeyer, J.L., 2001, Geologic map of the Cane quadrangle, Coconino County, northern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2366, scale 1:24,000, 7 p. [<http://geopubs.wr.usgs.gov/map-mf/mf2366/>]
- Billingsley, G.H., Wellmeyer, J.L., and Block, D.L., 2001, Geologic map of the House Rock quadrangle, Coconino County, northern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2364, scale 1:24,000, 8 p. [<http://pubs.usgs.gov/mf/2001/2364/>]
- Billingsley, G.H., and Wellmeyer, J.L., 2003, Geologic map of the Mount Trumbull 30' x 60' quadrangle, Mohave and Coconino Counties, northwestern Arizona: U.S. Geological Survey Geologic Investigations Series Map I-2766, scale 1:100,000, 36 p. [<http://pubs.usgs.gov/imap/i2766/>]
- Billingsley, G.H., and Workman, J.B., 2000, Geologic map of the Littlefield 30' x 60' quadrangle, Mohave County, northwestern Arizona: U.S. Geological Survey Geologic Investigations Series Map I-2628, scale 1:100,000, 25 p. [<http://pubs.usgs.gov/imap/i2628/>]
- Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic Systems of the Rocky Mountain region, USA: Society of Sedimentary Geology Meeting, Denver, Colo., p. 273-298.
- Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau: *in* Longman, M.W., and Sonnenfeld, M.D., eds., Paleozoic Systems of the Rock Mountain Region, Rocky Mountain Section, SEPM Society of Sedimentary Geology, p. 405-426.
- Blakey, R.C., and Ranney, Wayne, 2008, Ancient landscapes of the Colorado Plateau: Grand Canyon, Grand Canyon Association, 156 p.
- Bush, A.L., 1983, Geologic map of the Vermilion Cliffs-Paria Canyon Instant Study Area and adjacent wilderness study Areas, Coconino County, Arizona, and Kane County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1475-A, scale 1:62,500.

- Colbert, E.H., and Mook, C.C., 1951, The ancestral crocodilian *Protosuchus*: American Museum of Natural History Bulletin, v. 97, part. 3, p. 149-182.
- Cooley, M.E., Harshbarger, J.W., Akers, J.P., and Hardt, W.F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, Plate 1 (Sheet 2 of 9), p. A1-A61.
- Detterman, J.S., 1956a, Photogeologic map of the Emmett Wash NE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-190, scale 1:24,000.
- Detterman, J.S., 1956b, Photogeologic map of the Lee's Ferry SW quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-189, scale 1:24,000.
- Doelling, H.D., Blackett, R.E., Hamblin, A.H., Powell, J.D., and Pollock, G.L., 2000, Geology of Grand Staircase-Escalante National Monument, Utah, in Sprinkel D.A., Chidsey, T.C., and Anderson, P.B., eds., Geology of Utah's Parks and Monuments: Salt Lake City, Utah, Utah Geological Association Millennium Guidebook, Publication 28, p. 189-232.
- Fisher, W.L., 1961, Upper Paleozoic and lower Mesozoic stratigraphy of Parashant and Andrus Canyons, Mohave County, northwestern Arizona: Lawrence, Kans., University of Kansas, Ph.D. dissertation, 345 p.
- Gregory, H.E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geological Survey Professional Paper 220, 200 p.
- Haynes, D.D., and Hackman, R.J., 1978, Geology, structure, and uranium deposits of the Marble Canyon 1° x 2° quadrangle, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1003, scale 1:250,000.
- Harshbarger, J.W., Repenning, C.A., and Irwin, J.H., 1958, Stratigraphy of the uppermost Triassic and Jurassic rocks of the Navajo Country, in Anderson, R.Y., and Harshbarger, J.W., eds., Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geological Society 9<sup>th</sup> Field Conference, 205 p.
- Huntoon, P.W., 1990, Phanerozoic structural geology of the Grand Canyon, in Beus, S.S., and Morales, Michael, eds., Grand Canyon Geology: Oxford and New York, Oxford University Press, and Flagstaff, Arizona, Museum of Northern Arizona Press, p. 261-310.
- Huntoon, P.W., 2003, Post-Precambrian tectonism in the Grand Canyon region, chap. 14, in Beus, S.S., and Morales, Michael, eds., Grand Canyon Geology (2d ed.): New York and Oxford, Oxford University Press, p. 222-259.
- Huntoon, P.W., Billingsley, G.H., Sears, J.W., Ilg, B.R., Karlstrom, K.E., Williams, M.L., and Hawkins, D.P., 1996, Geologic map of the eastern part of the Grand Canyon National Park, Arizona: Grand Canyon, Arizona, Grand Canyon Association and Flagstaff, Arizona, Museum of Northern Arizona, scale 1:62,500.
- Lucas, S.G. and Tanner, L. H., 2006, Fossil vertebrates and the position of the Triassic-Jurassic boundary: Journal of Vertebrate Paleontology, v. 26, no. 3, 91 p.
- Lucchitta, Ivo, 1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region: Tectonophysics, v. 61, p. 63-95.
- Lucchitta, Ivo, 1990, History of the Grand Canyon and of the Colorado River in Arizona, in Beus, S.S., and Morales, Michael, eds., Grand Canyon Geology: Oxford and New York, Oxford University Press, p. 260-274.
- Marshall, C.H., 1956a, Photogeologic map of the Jacob Lake NE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-194, scale 1:24,000.
- Marshall, C.H., 1956b, Photogeologic map of the Paria Plateau SE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-191, scale 1:24,000.
- Martin, Harriet, and Barrick, J.E., 1999, Conodont biostratigraphy, chap. F: in Billingsley, G.H., and Beus, S.S., eds., Geology of the Surprise Canyon Formation of the Grand Canyon, Arizona: Flagstaff, Ariz., Museum of Northern Arizona Press, Bulletin no. 61, p. 97-115.
- Marzolf, J.E., 1991, Lower Jurassic unconformity (J-0) from the Colorado Plateau to the eastern Mojave Desert—Evidence of a major tectonic event at the close of the Triassic: Geology, v. 19, p. 320-323.
- McKee, E.D., 1954, Stratigraphy and history of the Moenkopi Formation of Triassic age: Geological Society of America Memoir, 61, 133 p.
- McKee, E.D., 1963, Nomenclature for lithologic subdivisions of the Redwall Limestone, Arizona: U.S. Geological Survey Professional Paper 475-C, p. C21-C22.
- McKee, E.D., 1982, The Supai Group of Grand Canyon: U.S. Geological Survey Professional Paper 1173, 504 p.
- McKee, E.D., and Gutschick, R.C., 1969, History of the Redwall Limestone of northern Arizona: Geological Society of America Memoir, v. 114, 726 p.
- McQueen, Kathleen, 1956, Photogeologic map of the House Rock Spring SE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-199, scale 1:24,000.
- Minard, J.P., 1956a, Photogeologic map of the Emmett Wash NW quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-192, scale 1:24,000.

- Minard, J.P., 1956b, Photogeologic map of the Tanner Wash NW quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-193, scale 1:24,000.
- Petersen, R.G., 1959, Preliminary Geologic map of the Emmett Wash NE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-215, scale 1:24,000.
- Petersen, R.G., 1961, Preliminary Geologic map of the Paria Plateau SE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-196, scale 1:24,000.
- Petersen, R.G., and Wells, J.D., 1961, Preliminary Geologic map of the Emmett Wash NW quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-197, scale 1:24,000.
- Peterson, Fred, and Pipiringos, G.N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic Formations, southern Utah and northern Arizona: U.S. Geological Survey Professional Paper 1035-B, 43 p.
- Phoenix, D.A., 1963, Geology of the Lees Ferry area, Coconino County, Arizona: U.S. Geological Survey Bulletin, 1137, 86 p., plate 1, scale 1:24,000.
- Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.
- Ranney, Wayne, 2005, Carving Grand Canyon—Evidence, Theories, and Mystery: Frazier, Pam, ed., Grand Canyon, Ariz., Grand Canyon Association, 160 p.
- Rawson, R.R., and Turner, C.E., 1974, The Toroweap Formation—A new look, *in* Karlstrom, T.N.V., Swann, G.A., and Eastwood, R.L., eds., Geology of northern Arizona with notes on archaeology and paleoclimate, Part 1, Regional studies: Geological Society of America, Rocky Mountain Section Meeting, Flagstaff, Ariz., p. 155-190.
- Repenning, C.A., Cooley, M.E., and Akers, J.P., 1969, Stratigraphy of the Chinle and Moenkopi Formations, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Professional Paper 521-B, 34 p.
- Riggs, N.R., and Blakey, R.C., 1993, Early and Middle Jurassic paleogeography and volcanology of Arizona and adjacent areas, *in* Dunne, George, and McDougall, Kristin, eds., Mesozoic paleogeography of the western United States-II: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 71, p. 347-375.
- Sargent, C.G., and Philpott, 1987, Geologic map of the Kanab quadrangle, Kane County, Utah and Mohave and Coconino Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1603, scale 1:62,500.
- Schleh, E.E., 1966, Stratigraphic section of Toroweap and Kaibab Formations in Parashant Canyon, Arizona: Arizona Geological Society Digest, v. 8, p. 57-64.
- Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: *The Mountain Geologist*, v. 28, no. 1, p. 9-24.
- Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p.
- Tanner S.G. and Lucas, L.H., 2007, The non-marine Triassic-Jurassic boundary in the Newark Supergroup of eastern North America: *Earth-Science Reviews*, v. 84, no. 1-2, p. 1-20.
- Timmons, J.M., Karlstrom, K.E., Heizler, M.T., Bowring, S.A., Gehrels, G.E., and Crossey, L.J., 2005, Tectonic inferences from the ca. 1254-1100 Ma Unkar Group and Nankoweap Formation, Grand canyon: Intracratonic deformation and basin formation during protracted Grenville orogenesis; *Geological Society of America Bulletin*, v. 117, no. 11/12, p. 1573-1595.
- Timmons, J.M., Karlstrom, Karl, Pederson, Joel, and Anders, Matt., 2007, Geologic map of the Butte Fault/East Kaibab Monocline area, eastern Grand Canyon, Arizona: Love, J.C., and Price, L.G., eds., Grand Canyon, Arizona, Grand Canyon Association in cooperation with the New Mexico Bureau of Geology and Mineral Resources, scale 1:24,000, 2 plates.
- U.S. Department of the Interior, 2006, Bureau of Land Management, Arizona Strip Visitor Map, Arizona: St. George, Utah, Bureau of Land Management – National Applied Resource Science Center, scale 1:168,960.
- Wells, J.D., 1958, Preliminary geologic map of the house Rock Spring NE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-188, scale 1:24,000.
- Wells, J.D., 1959, Preliminary geologic map of the House Rock Spring SE quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-189, scale 1:24,000.
- Wells, J.D., 1960, Stratigraphy and structure of House Rock Valley area, Coconino County, Arizona: U.S. Geological Survey Bulletin 1081-D, plate 4, scale 1:48,000.
- Wenrich, K.J., and Huntoon, P.W., 1989, Breccia pipes and associated mineralization in the Grand Canyon region, northern Arizona, *in* Elston, D.P., Billingsley, G.H., and Young, R.A., eds., Geology of Grand Canyon, northern Arizona (with Colorado River guides) Lees Ferry to Pierce Ferry, Arizona: American Geophysical Union, Washington, D.C., 28<sup>th</sup> International Geological Congress Field Trip Guidebook T115/T315, p. 212-218.
- Wenrich, K.J., and Sutphin, H.B., 1989, Lithotectonic setting necessary for formation of a uranium-rich, solution-collapse breccia-pipe province, Grand Canyon region, Arizona: U.S. Geological Survey Open-File Report 89-0173, 33 p.

Wilson, E.D., Moore, R.T., and O'Haire, R.T., 1960, Geologic map of Coconino County: Arizona Bureau of Mines, University of Arizona, scale 1:375,000.  
Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of the State of Arizona: Arizona Bureau of Mines, University of Arizona, scale 1:500,000.